ESTIMATE FOR A VERY LARGE OIL SPILL

FROM AN EXPLORATION WELL

IN THE CHUKCHI SEA OCS PLANNING AREA

NW ALASKA

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Appendix D. Estimate for a Very Large Oil Spill

1. Purpose of Chukchi Sea VLOS Well Analysis

This document explains the methods by which BOEMRE created a simulation of a very large discharge event for a hypothetical reservoir in the Chukchi Sea. The purpose of creating this simulation is to provide a basis for evaluating the environmental consequences from a low probability, high impacts event—a high-volume and sustained blowout leading to a very large oil spill (VLOS) in the Chukchi Sea. To ensure that all potential environmental consequences of a VLOS are considered, this simulation ascertains the highest flow rate of hydrocarbons and the aggregate discharge that could plausibly occur from any known prospect in the Sale 193 lease area.

2. Selection of Geologic Model for Chukchi Sea VLOS Well

Among the prospects identified by BOEMRE seismic studies within the area of Chukchi Sea Lease Sale 193, a candidate prospect has been adopted as the site for a hypothetical blowout and discharge of oil into the marine environment from an exploration well. This candidate prospect was selected to maximize key geological characteristics that drive high flow rates—principally a thick reservoir offering high permeability—and was modeled for potential discharge volumes in a blowout event. The particular prospect is not known to contain oil or to offer rocks capable of performing as petroleum reservoirs. The geological model for the prospect is assumed to be a successful case and the considerable geological risk associated with the prospect is ignored. Lastly, the extremely low probability of a discharge event of the modeled magnitude is not considered in the analysis.

3. Point of Discharge into Marine Environment

The VLOS is assumed to originate from an exploration well at an unspecified location in the Chukchi Sea planning area and within the area identified in Figure D-1. The modeled point of discharge is the top of a blowout preventer coincident with the seafloor or "mudline" 131 ft below mean sea level (the base of the blowout preventer is placed at the bottom of a cellar ~40 ft deep for protection from iceberg keels; the top of the blowout preventer nearly reaches the seafloor). The association of the point of discharge with the blowout preventer is consistent with the BOEMRE protocol for determinations of worst-case discharges for proposed exploration and development wells.

4. Description of Relief Well Model

The oil discharge is assumed to terminate with the completion of a relief well after 74 days of flow, the longest time period among three possible scenarios described in Table D-1. The relief well scenarios were constructed by petroleum engineers within the office of Field Operations in the Alaska office of BOEMRE. The 74-day spill scenario assumes that a drilling platform located outside Alaska Arctic and somewhere in the North Pacific must be taken off an active project, re-fitted, and mobilized to the blowout site in the Chukchi Sea. No scenario for a "top-kill" or re-establishment of well flow control using the existing equipment and surface control techniques (often accomplished within a day) is entertained in this study.

5. The Gemini Solutions AVALON/MERLIN Computer Model

The computer model used to forecast the flow of fluids out of the Chukchi Sea VLOS well is a state-of-the-art proprietary commercial program by Gemini Solutions, Inc. of Richmond, Texas (http://www.geminisi.com/). The program is constructed as a desktop finite-difference simulator that divides the active flow system into many small cells and then iterates through time-increments of flow with re-assessments that successively modify the state of each cell in the flow system. Finite-difference models use approximations to relevant differential equations to calculate changes (e.g., pressures, fluid saturations, etc. in the case of fluid flow) within each cell. The incremental approach minimizes approximation errors by confining calculations to single cells and makes it possible to quantify behavior across complex systems with internal discontinuities (e.g., flow from reservoir to open well to casing to production manifold to pipeline, etc.). The model is robust, offering the capability to model fluid behavior through rank compositional data or through measured physical properties that can be used to forecast (through correlations) other properties.

The Gemini model consists of two components, "*AVALON*" and "*MERLIN*", that respectively simulate: (1) flow up a system of tubular passages (or "tubulars") and (2) inflow (into the bottom of a well) from a pressurized porous reservoir. The correlative capacities of these two components of the flow system determine the discharge rate that can be achieved through the exit point at the top of the well. In theory, the maximum possible discharge rate can be limited by either the aggregate outflow capacity of the tubulars or by the reservoir inflow capacity at the base of the well. In the design of development wells and take-away pipelines, these two components of the flow system (the tubulars and the reservoir) are balanced to achieve the most efficient long-term recovery of formation hydrocarbons from the field. For a high-yield reservoir like that modeled for the Chukchi Sea VLOS well, the discharge rate is usually limited by the choke effect of wellbore tubulars that are insufficient to accommodate inflow from the reservoir.

The flow up the open (uncased) wellbore and the casing is governed by the tubular sizes (diameter and length), roughness, frictional resistance, the driving formation pressure, and the density characteristics and thermal effects of the multiphase oil-gas-water mix (ranging from gassy liquid[s] to wet gas) moving upward through the wellbore. Flowing bottom-hole pressures at the base of the tubulars are a function of the aggregate density of the multiphase wellbore fluids, frictional and gravitational resistance to flow, ambient pressure (wellhead exterior), and reservoir pressure.

The inflow from the reservoir formation is chiefly governed by pore system size and connectivity, formation pressure, drive mechanism, fluid compositions, fluid properties at reservoir conditions of pressure and temperature, and length of the wellbore segment passing through the reservoir formation.

6. The Chukchi Sea VLOS Wellbore Design Model

The Chukchi Sea VLOS well has an assumed design standardized to wells drilled to targets at comparable depths on the Chukchi and Beaufort shelves in the past. Several strings of casing ranging from 30 to 13-3/8 inches in diameter are assembled and cemented in place as the well is deepened with a final interior string of 9-5/8 inch casing extending from the shale seal formation above the reservoir formation to the base of the blowout preventer. In practice, any problems with wellbore instability (spalling or caving of the wall of the wellbore) in the course of drilling might require a smaller casing string. However, the model assumes that no problems of this nature are encountered below either the 13-3/8 inch or 9-5/8 inch casing strings.

The blowout preventer rests in a cellar approximately 40 ft deep and 20 ft in diameter. The top of the blowout preventer reaches nearly to the mudline (sufficient distance below the mudline to be protected from iceberg keels, a requirement for the Arctic OCS). For purposes of the VLOS model, the 9-5/8-inch casing is assumed to extend up to the mudline. In effect, the blowout preventer is assumed to offer no resistance to flow but is simply an extension of the casing. The pressures exerted by the atmosphere and the seawater column together contribute approximately 73 psi to the flowing bottom-hole pressure that resists inflow at the face of the reservoir formation in the bottom part of the VLOS well. The 9-5/8-inch casing is assumed to have an internal diameter of 8.535 inches and this value partly controls throughput capacity. The wellbore below the casing is open (uncased) and passes through the reservoir formation to total depth. The open wellbore is assumed to be drilled with a bit 8.5 inches in diameter to a depth of 9,000 ft, with washout enlarging the wellbore to ~130% of gauge (~11 inches). The washout assumption has the effect of increasing discharge rate. Each segment of the flow path is also assigned a length and a roughness factor to evaluate frictional effects.

7. Proprietary Data in Chukchi Sea VLOS Well Model

Certain data related to the actual prospect modeled are uniquely derived from proprietary seismic data and cannot be revealed without compromising intellectual property rights and causing harm to the financial interests of leaseholders. These data include reservoir depth (and related details of casing design), specific well location, and targeted formation(s). In any case, these proprietary data are not directly relevant to the research issue at hand—the potential environmental impact of a sustained oil discharge from any source—and their exclusion from specific reference in this study does not detract from the conclusions of the study.

8. Darcy Radial Flow Equation and Basic Data for Discharge Model

The most important variables for the reservoir inflow component of the discharge model include the aggregate thickness of flow units (h), initial (pore) pressure (p_i), permeability (k_o) of the reservoir formation, and oil viscosity (μ_o). Inflow rates are particularly sensitive to permeability, which at extremes can vary across 7 orders of magnitude (0.01-1,000 md) or greater. Other important variables include oil viscosity and reservoir pressure. However, other important variables can vary by several factors.

The flow of fluids out of a reservoir and into a well, or “inflow”, is grossly governed by the Darcy radial flow equation, as summarized in its simplest form for an oil reservoir below. The purpose of including the equation here is to illustrate the roles of the key variables in determining flow rate, denoted in the convention of petroleum engineers as “q_o”. Note that no flow-limiting constraints are imposed upon outflow by the well tubular configuration above the reservoir in the basic Darcy equation.

Darcy radial flow *(steady-state) equation from Ahmed (2010, p. 435, equation 6-144)*

$$q_o = \frac{0.00708 * k_o * h * (p_i - p_{wf})}{\mu_o * B_{oi} * ((\ln r_e/r_w) + S)}$$

where
q_o= oil flow rate, barrels/day;
k_o=permeability to oil, md, typically 0.01- >1,000 md;
h= thickness, ft, typically 10-200 ft;
p_i = initial reservoir pore pressure, psi, typically 1,500-20,000 psi;
p_{wf} = bottom-hole flowing pressure, psi, typically 300-8,000 psi;
μ_o = oil viscosity, cp, typically 0.1 to 30.0 cp;
B_{oi} = oil formation volume factor, reservoir bbls per stock-tank bbl, typically 1.0-3.0;
r_e = drainage radius, ft, typically 1,000-20,000 ft;
r_w = radius of well, ft, typically 0.35 to 0.73 ft;
S = skin factor, dimensionless, typically 0-500.

Many other variables of lesser importance that do not appear in the Darcy radial flow equation are required for the *AVALON/MERLIN* reservoir inflow model. Table D-2 summarizes some of the key reservoir and fluid properties and model parameters that formed the input data to the reservoir inflow model. Variables that appear in the Darcy radial flow equation above are highlighted.

In the Chukchi Sea VLOS well oil discharge model, no factors related to the near-wellbore alteration of the reservoir formation that might limit flow rate or arrest the discharge were employed. The “skin factor (S)" shown in the Darcy radial flow equation above usually quantifies the plugging of reservoir pores (by drilling fluid solids) that often accompanies the drilling of a well; for the VLOS model "S" is set to zero (no effect on discharge rate). The model further assumes no influx into the well of brines from the aquifer beneath the oil pool or from separate brine-bearing sandstones that intersect the wellbore. In addition, no "bridging" or collapse of the open segment of the wellbore was assumed to restrict or terminate flow. No near-wellbore reservoir boundaries (such as faults) were invoked to limit the potential drainage area.

Reservoir pressure and temperature are forecast from data collected in the 5 exploration wells in the Chukchi Sea in the 1989-1991 drilling program that followed the 1988 lease sale (109). Reservoir formation identification at the subject prospect is a result of extending formation boundaries away from well control both offshore and onshore through a grid of proprietary seismic data, including recently-acquired three-dimensional (3D) seismic data. Estimates for reservoir porosity and permeability are based on regional analog fields and well penetrations outside of oil fields.

The aggregate thickness of flow units is based upon a synthesis of proprietary seismic mapping that defines the shape of a capture volume, or trap, which is assumed to be completely filled with oil. The seismic mapping locates and measures the point of the maximum vertical thickness of the capture volume, which is where the VLOS well is sited. Therefore, the exact location of the VLOS well represents proprietary information and is not disclosed. The vertical thickness of the oil-filled capture volume is reduced to an aggregate flow unit thickness by the expected ratio of porous flow units to overall formation thickness as forecast from analog fields and well penetrations.

The area drained by the blowout event is assumed to be 160 acres (equivalent radius [r_e] surrounding well = 1,490 ft). The oil saturation model is based on the porosity and permeability models, assumptions about the texture (sorting, particle size) of the porous units in the reservoir formation, and reference to analog fields.

The oil discharged from the Chukchi Sea VLOS well is assumed to be low-sulfur 35° API crude oil like that recovered at the Klondike 1 well, here informally termed the "Klondike oil." The Klondike oil was recovered when the drill string was pulled out of the well to repair a plugged jet in the bit. The lifting of the drill string reduced wellbore pressure in the lower part of the well and thereby drew the oil out of the formation and into the wellbore. At the time of the bit repair trip, the part of the wellbore that was uncased or "open" extended from 9,093 ft to 9,916 ft md. This "swabbed" oil was subsequently circulated to the surface with drilling fluids and an unspecified quantity was collected as samples. The Klondike oil had a gravity of 35.3°API, a sulfur content of 0.18%, a ratio of *saturates:aromatics:non-hydrocarbons = 66.2:26.1:7.7, a ratio of normal paraffins:isoalkanes + cycloalkanes:aromatics:non-hydrocarbons = 22.4:43.8::26.1:7.7* (Klondike 1 well, 1989) and would be classified as a paraffinic-naphthenic oil (Tissot and Welte, Table IV.2.2, p. 418). The low-sulfur and high-gravity qualities of the Klondike oil resemble the Simpson, Umiat, Tarn, and Alpine oils of the North Slope of Alaska (Figure D-2a). However, unlike the Simpson, Umiat, and Tarn oils, the Klondike oil is isotopically "light" (or deficient [relatively more negative value for ΔC^{13}] in the content of the heavier carbon isotope C^{13} relative to C^{12}). The isotopic composition of the Klondike oil most resembles the Jurassic (Kingak Formation)-sourced oils of Alpine field and at the Kavearak Point well (Figure D-2b). However, the ratio of C^{29} Terpane/Hopane for the Klondike oil is 0.77; values exceeding 0.75 suggest contribution from marine carbonate (Peters et al., 2007, tbl. 3, p. 883 & 893), possibly pointing to the carbonates of the Triassic Shublik Formation as a second contributing source. The Klondike oil is assumed to represent the dominant (Triassic/Jurassic-sourced) petroleum system in the central Chukchi Sea because of its composition and because it was extracted from a sequence of rocks that includes very rich oil source rocks of the Shublik (Upper Triassic) and Fire Creek (Lower Triassic) Formations. No oil source rocks of Jurassic age were penetrated in the Klondike 1 well but such rocks are probably preserved in nearby areas flanking the Klondike structure.

The oil in the VLOS reservoir is assumed to be initially saturated (contains the maximum amount of dissolved gas possible at the inferred reservoir temperature and pressure). Therefore, the bubble-point pressure (pressure at which dissolved gas breaks out of solution and forms bubbles in the oil) is assumed to equal the initial reservoir pressure (pi). No significant gas cap is assumed to be present in order to maximize the vertical thickness of the oil column. The pressure-temperature model, the oil gravity, and the assumption of saturation then lead through various correlations and calculations to estimates for B_{oi} (oil volume factor, in reservoir barrels [rb] per surface or “stock tank” barrel [stb]), Rsi (dissolved gas content, in surface or standard cubic ft [scf] per stock tank barrel [stb]), μ_o (oil viscosity, in centipoise [cp]), reservoir oil density (g/cm^3), and static pressure gradient for reservoir oil (in psi/ft). In some basins, these types of data are sometimes available through laboratory “PVT” (pressure-volume tests at constant temperature) studies of oil recovered in nearby wells. However, for the Chukchi Sea VLOS well, no relevant PVT studies are available and many key fluid and rock parameters were of necessity obtained through estimates for pressure and temperature and use of industry-accepted correlations as published by many sources including Craft and Hawkins (1959), Standing (1977, and other references therein), McCain (1973, and references therein), and Ahmed (2010, and many references therein).

The drive mechanism for the blowout flow is assumed to be pressure depletion and expansion of exsolved solution gas. The estimate for specific gas gravity is based on analyses of gas samples obtained by tests at the Burger 1 and Popcorn 1 wells on the Chukchi shelf. Estimates for fluid and rock compressibility are based upon assumptions about rock consolidation, porosity, pressure, temperature, dissolved gas content, relative fluid saturations, and brine composition. The brine salinity is assumed to be similar to seawater and that assumption is supported by analyses of connate water recovered at the Burger 1 well. The estimate for brine viscosity is based upon the salinity assumption and reservoir temperature. The model-implied in-place oil volume (reduced to surface barrels) is calculated as 869 bbls/acre-ft, as shown at the bottom of Table D-2. Joining the implied in-place oil volume with thickness (h) and a 160-acre assumed drainage area indicates an in-place volume of 25,722,400 bbls of oil within the model drainage area. Probably less than half of this in-place oil could be recovered by a single well, even over decades of carefully-engineered production and enhanced recovery techniques. Only a very small fraction of this in-place oil will reach the surface during the hypothetical VLOS.

9. Discharge Model Results for the Chukchi Sea VLOS Well

Table D-3 and Figure D-3 summarize the results of the discharge model for the Chukchi Sea VLOS Well. Following the blowout, the oil discharge climbs rapidly to a maximum of 61,672 bbls/d during day 1. After peaking in day 1, Figure D-3 shows that the oil discharge rate declines rapidly through the first 40 days of flow as the reservoir is depressurized by approximately 1,400 psi (Table D-3). The decline in the flow rate flattens somewhat after day 40, finally falling to 20,479 bbls/d (33% of the day 1 peak rate) by day 74 when the near-wellbore reservoir pressure has fallen to 58% of the initial reservoir pressure (4,392 psi). As shown at the bottom of Table D-3, the cumulative oil discharge over the 74-day discharge period is 2,160,200 bbls. As shown in Table D-3, water production over the 74-day period is quite small (cumulative water: 28.8 bbls). The water discharge is limited because in the oil-saturated reservoir the small amount of water is bound to the walls of pores and because the relative permeability to oil is much higher. In addition, the model is designed to preclude any brine-saturated reservoir from direct contact with the wellbore.

10. Patterns of Fluid Discharges from the Chukchi Sea VLOS Well

The decline in discharge rates of both oil and gas during the early part of the flow period are on the order of 99% per year and reflect rapid de-pressurization of the reservoir near the wellbore. The oil discharge rate declines throughout the entire 74-day period. However, the gas discharge rate declines to a minimum of 19,513 Mcf/d on day 45 and then, despite continuing reservoir depressurization, reverses the decline and rises to 24,608 Mcf/d by the end of the 74-day period. This behavior is caused by the evolving compositions of the fluids that remain in the reservoir pore system as oil is withdrawn. One clue to how the reservoir contents are changing is the change in produced gas-oil ratio through the 74-day flow period, as discussed below.

The oil in the VLOS reservoir is estimated to be originally saturated with 930 scf/stb of dissolved (solution) gas and this is reflected by the identical initial produced gas-oil ratio of 930 scf/stb in the flow model (time 0.1 days, Table D-3). As shown in Table D-3 and Figure D-3, the produced gas-oil ratio falls from the initial value of 930 scf/stb into a protracted minimum of approximately 757 scf/stb from day 15 to day 27, thereafter rising steadily to 1,202 scf/stb by day 74. This is a consequence of the increasing enrichment or "saturation" of the reservoir pore system with bubbles of free gas as pressure declines and dissolved gas breaks out of the oil and forms a separate phase in the centers of pores. At the onset of flow, and through the first 27 days of flow, gas bubbles are forming within the reservoir near the wellbore, but high oil saturation and correlative low relative permeability to gas blocks the movement of the gas bubbles through the pores in the reservoir and thence to the well. As oil flow continues, the oil saturation declines while gas saturation rises and gas eventually becomes the dominant phase. By day 27, a large volume of the reservoir near the wellbore hosts high free gas saturations and gas can easily flow to the wellbore. Thus, we observe that the gas rate and the produced gas-oil ratio both steadily rise, to 24,608 Mcf/d and 1,202 scf/stb respectively, by the end of the 74-day flow period. Essentially, the original VLOS oil reservoir is being converted to a gas reservoir. Ultimately, beyond the 74-day period shown in Figure D-3, gas production will peak and then decline as the reservoir drains to complete depletion of extractable oil and gas.

TABLES

Table D-1. Estimates for time periods required to drill a relief well and to kill the discharge at the Chukchi Sea VLOS well (provided by BOEMRE AKOCSR Field Operations office). Model 3 provides the largest and most protracted discharge and forms the basis for the present study.

Relief Well Models for Chukchi Sea VLOS Well

1. Use of Original Drilling Platform and Equipment to Drill Relief Well

Activity	Time Estimate (days)
Cleanup and Re-Supply of Original Vessel	5
Construction of Relief Well Cellar *	7
Drilling of Relief Well	18
Killing of VLOS (Original) Well	5
Weather Downtime *	4
Total Required Time	*39*

2. Use of Second Drilling Platform and Equipment Pre-Positioned In-Theater (Within Chukchi Sea) for Relief Well

Activity	Time Estimate (days)
Plug and Temporarily Abandon Well Being Drilled by Second Drilling Platform	5
Cleanup and Re-Supply of Relief Well Vessel	5
Transport of Relief Well Rig to VLOS Well Site	2
Construction of Relief Well Cellar *	7
Drilling of Relief Well	18
Killing of VLOS (Original) Well	5
Weather Downtime *	4
Total Required Time	*46*

3. Use of Second Drilling Platform and Equipment from Northern

Activity	Time Estimate (days)
Plug and Temporarily Abandon Well Being Drilled by Second (Relief Well) Drilling Platform	5
Cleanup of Relief Well Vessel (Performed En Route-No Additional Time)	0
Transport of Relief Well Rig to VLOS Well Site	30
Re-Supply of Relief Well Vessel	5
Construction of Relief Well Cellar *	7
Drilling of Relief Well	18
Killing of VLOS (Original) Well	5
Weather Downtime *	4
Total Required Time	*74*

** estimates based upon previous operations in the area*

Table D-2. Selected key input variables for reservoir inflow simulation element of Chukchi Sea VLOS well discharge model using AVALON/MERLIN software.

Initial Reservoir Pressure ($\mathbf{p_i}$, psi)	4,392	Bubble Point Pressure (psi)	4,392
Flowing Bottom-Hole Pressure ($\mathbf{p_{wf}}$, psi) - Modeled by *AVALON/MERLIN*	1,853 - 3,760	Oil Viscosity ($\boldsymbol{\mu_o}$, cp)	0.47
Reservoir Temperature, °F (°R)	176 (636)	Skin Factor (**S**)	0
Reservoir Porosity (fraction of rock)	0.21	Reservoir Oil Density (g/cm^3)	0.68
Reservoir Permeability ($\mathbf{k_o}$, md)	400	Static Pressure Gradient of Reservoir Oil (psi/ft)	0.295
Aggregate Thickness Flow Units (**h**, ft)	185	Specific Gas Gravity (Air=1.0)	0.6
Drainage Radius ($\mathbf{r_e}$, ft)	1,490	Formation Compressibility, Cf (v/v/psi*10^{-6})	3.6
Well Radius at Reservoir ($\mathbf{r_W}$, ft)	0.46	Oil Compressibility, Co (v/v/psi*10^{-6})	13.031
Initial Oil Saturation (fraction of porosity)	0.76	Brine Compressibility, Cw (v/v/psi*10^{-6})	3.25
Critical Oil Saturation (fraction of porosity)	0.2	Total Compressibility, Ct (v/v/psi*10^{-6})	14.284
Oil Gravity (°API)	35	Brine Salinity (ppm NaCl)	35,000
Initial **Boi** or FVF (rb/stb)	1.425	Brine Viscosity (cp)	0.37
Initial Rsi or GOR (scf/stb)	930	Implied In-Place Oil Volume (bbls/acre-ft at 1 atm. and 60°F)	869

psi, pounds per square inch; °R, °Rankine (=°F+460); Boi, oil volume factor (aka FVF or formation volume factor); rb/stb, reservoir barrels per stock-tank barrel of oil (at 1 atm. and 60°F); Rsi, gas saturation (aka GOR or gas-oil ratio); scf/stb, standard cubic feet of gas per stock-tank barrel of oil (at 1 atm. and 60°F); cp, centipoise; model-implied in-place oil=7,758.38 bbls/acre-ft(0.21*(0.76)/1.425). Highlighted variables appear in the Darcy radial flow equation.*

Table D-3. Results of AVALON/MERLIN discharge model for Chukchi Sea VLOS well over maximum (74-day) time period estimated for mobilization, drilling, and completion of a relief well.

Time (days)	Oil Discharge Rate (bbls/d)	Gas Discharge Rate (Mcf/d)	Producing Rsi (GOR) Gas-Oil Ratio (scf/stb)	Water Discharge Rate (bbls/d)	Cumulative Oil Discharge (Mbbls)	Cumulative Gas Discharge (MMcf)	Cumulative Water Discharge (bbls)	Near-Wellbore Reservoir Pressure (psi)
0	0	0	930	0	0	0.0	0	4,392
0.1	50,671	47,124	930	0.06	5.1	4.7	0.0	4,168
1	61,672	50,677	822	0.16	61.8	52.2	0.1	3,937
2	57,485	46,357	806	0.18	120.5	99.8	0.3	3,875
3	53,987	43,035	797	0.20	175.1	143.5	0.5	3,827
4	52,246	41,030	785	0.23	226.1	183.9	0.7	3,777
5	48,669	38,101	783	0.23	274.8	222.0	1.0	3,747
6	46,581	36,312	780	0.25	321.4	258.4	1.2	3,707
7	45,036	34,931	776	0.26	366.4	293.3	1.5	3,666
8	43,596	33,607	771	0.27	410.0	326.9	1.7	3,627
9	42,239	32,343	766	0.28	452.2	359.2	2.0	3,591
10	40,889	31,100	761	0.29	493.1	390.3	2.3	3,558
11	39,529	29,923	757	0.29	532.6	420.3	2.6	3,528
12	38,306	28,974	756	0.30	570.9	449.2	2.9	3,499
13	37,219	28,148	756	0.30	608.2	477.4	3.2	3,473
14	36,364	27,583	759	0.31	644.5	505.0	3.5	3,445
15	35,580	27,035	760	0.32	680.1	532.0	3.8	3,420
16	34,930	26,628	762	0.33	715.0	558.6	4.2	3,394
17	34,316	26,178	763	0.33	749.4	584.8	4.5	3,370
18	33,750	25,767	763	0.34	783.1	610.6	4.8	3,347
19	33,199	25,330	763	0.34	816.3	635.9	5.2	3,325
20	32,662	24,885	762	0.35	849.0	660.8	5.5	3,304
21	32,130	24,436	761	0.35	881.1	685.2	5.9	3,284
22	31,608	23,995	759	0.35	912.7	709.2	6.2	3,265
23	31,094	23,577	758	0.35	943.8	732.8	6.6	3,247
24	30,596	23,178	758	0.36	974.4	756.0	6.9	3,230
25	30,115	22,800	757	0.36	1,004.5	778.8	7.3	3,213
26	29,648	22,443	757	0.36	1,034.2	801.2	7.7	3,197
27	29,200	22,110	757	0.36	1,063.4	823.3	8.0	3,181
28	28,750	21,788	758	0.36	1,092.1	845.1	8.4	3,165
29	28,319	21,499	759	0.36	1,120.4	866.6	8.7	3,150
30	27,917	21,245	761	0.37	1,148.3	887.9	9.1	3,136
31	27,539	21,029	764	0.37	1,175.9	908.9	9.5	3,121
32	27,166	20,806	766	0.37	1,203.0	929.7	9.9	3,106
33	26,805	20,599	768	0.37	1,229.9	950.3	10.2	3,092
34	26,452	20,415	772	0.37	1,256.3	970.7	10.6	3,079
35	26,124	20,256	775	0.38	1,282.4	991.0	11.0	3,065
36	25,817	20,115	779	0.38	1,308.2	1011.1	11.4	3,052
37	25,534	20,006	784	0.38	1,333.8	1031.1	11.7	3,038
38	25,250	19,886	788	0.38	1,359.0	1051.0	12.1	3,025
39	24,974	19,787	792	0.39	1,384.0	1070.8	12.5	3,012
40	24,719	19,707	797	0.39	1,408.7	1090.5	12.9	2,999
41	24,474	19,637	802	0.39	1,433.2	1110.1	13.3	2,986
42	24,251	19,595	808	0.39	1,457.4	1129.7	13.7	2,973
43	24,034	19,552	814	0.40	1,481.5	1149.2	14.1	2,961
44	23,821	19,522	820	0.40	1,505.3	1168.8	14.5	2,948
45	23,620	19,513	826	0.40	1,528.9	1188.3	14.9	2,936
46	23,434	19,518	833	0.41	1,552.4	1207.8	15.3	2,923
47	23,259	19,531	840	0.41	1,575.6	1227.3	15.7	2,911
48	23,110	19,579	847	0.42	1,598.7	1246.9	16.1	2,898
49	22,946	19,617	855	0.42	1,621.7	1266.5	16.5	2,885
50	22,797	19,682	863	0.42	1,644.5	1286.2	17.0	2,873
51	22,665	19,765	872	0.43	1,667.1	1306.0	17.4	2,860
52	22,543	19,856	881	0.43	1,689.7	1325.8	17.8	2,847
53	22,434	19,972	890	0.44	1,712.1	1345.8	18.3	2,835
54	22,325	20,098	900	0.44	1,734.4	1365.9	18.7	2,822
55	22,228	20,252	911	0.45	1,756.7	1386.2	19.2	2,809
56	22,150	20,425	922	0.46	1,778.8	1406.6	19.6	2,795
57	22,042	20,566	933	0.46	1,800.9	1427.1	20.1	2,783
58	21,918	20,699	944	0.47	1,822.8	1447.8	20.6	2,770
59	21,807	20,869	957	0.47	1,844.6	1468.7	21.0	2,758
60	21,688	21,030	970	0.48	1,866.3	1489.7	21.5	2,745
61	21,580	21,203	983	0.48	1,887.8	1510.9	22.0	2,733
62	21,475	21,381	996	0.49	1,909.3	1532.3	22.5	2,720
63	21,369	21,566	1,009	0.49	1,930.7	1553.9	23.0	2,708
64	21,284	21,804	1,024	0.50	1,952.0	1575.7	23.5	2,695
65	21,193	22,032	1,040	0.51	1,973.2	1597.7	24.0	2,683
66	21,112	22,276	1,055	0.51	1,994.3	1620.0	24.5	2,670
67	21,033	22,532	1,071	0.52	2,015.3	1642.5	25.0	2,657
68	20,955	22,799	1,088	0.53	2,036.3	1665.3	25.5	2,644
69	20,868	23,078	1,106	0.53	2,057.1	1688.4	26.1	2,632
70	20,777	23,350	1,124	0.54	2,077.9	1711.8	26.6	2,619
71	20,693	23,637	1,142	0.55	2,098.6	1735.4	27.2	2,606
72	20,615	23,934	1,161	0.55	2,119.2	1759.3	27.7	2,594
73	20,539	24,248	1,181	0.56	2,139.8	1783.6	28.3	2,581
74	20,479	24,608	1,202	0.57	2,160.2	1808.2	28.8	2,567

Mcf/d, thousands of cubic feet per day; scf/stb, standard cubic feet or gas per stock-tank barrel of oil at 1 atmosphere (101.6 kilopascals) and 60°F (15.6°C) or surface conditions; Mbbls, thousands of barrels; MMcf, millions of cubic feet; psi, pounds per square inch (6.895 kiloipascals). "Near-Wellbore Reservoir Pressure" represents the formation pressure in the cell penetrated by the well.

FIGURES

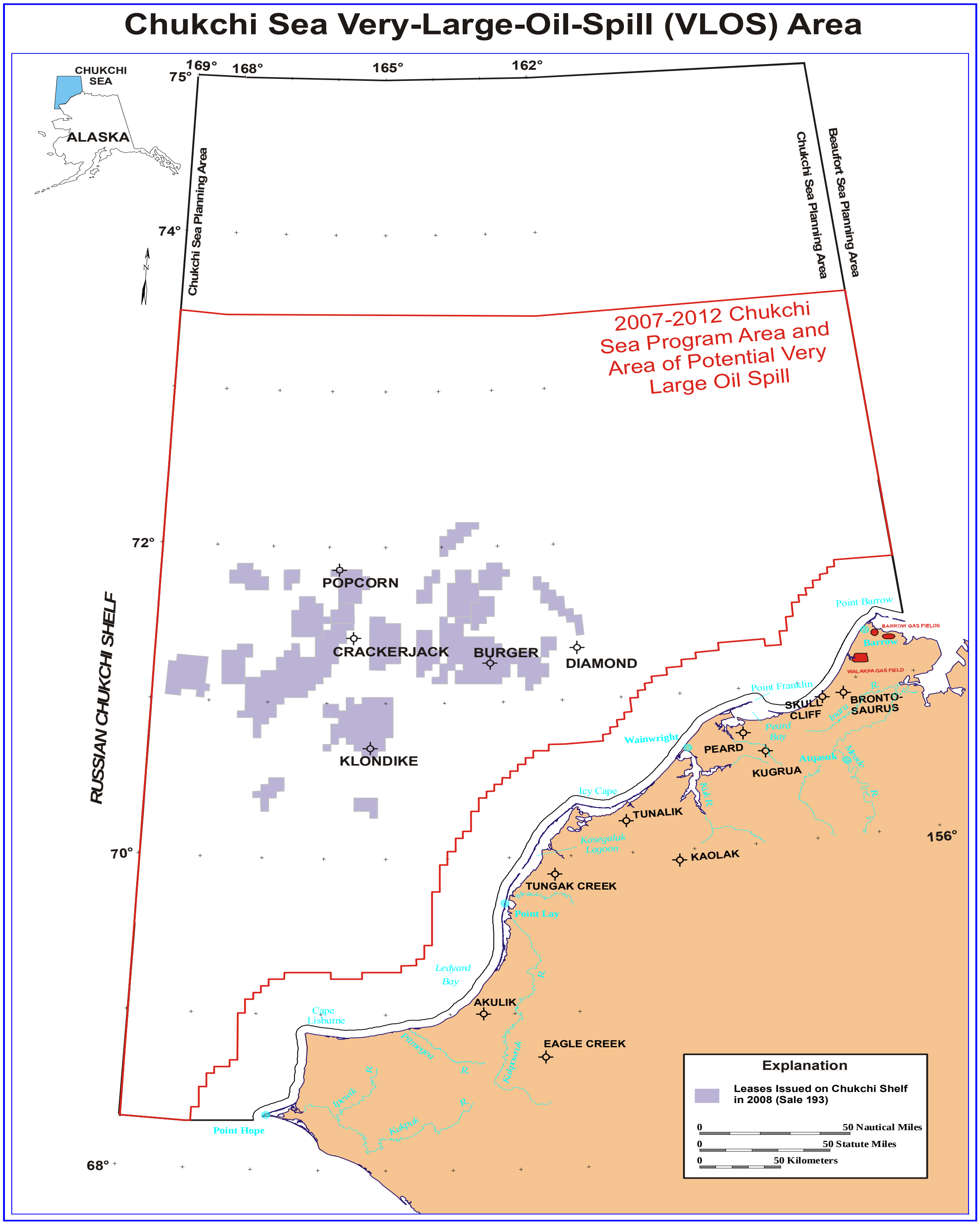

Figure D-1. Map of Chukchi Sea planning area with Sale 193 leased acreage.

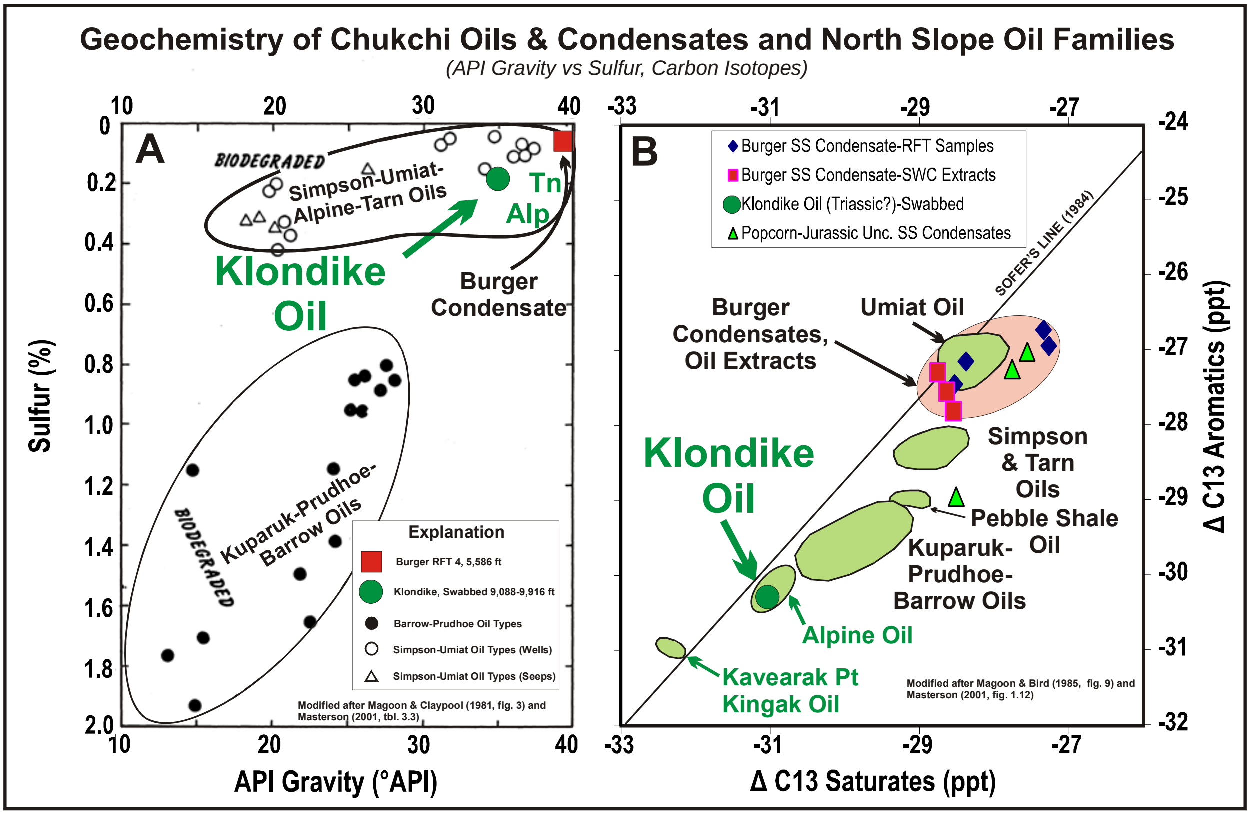

Figure D-2. A) Klondike oil gravity and sulfur content as compared to Burger condensates and North Slope oil types (Tn = Tarn oil; Alp = Alpine oil); B) Isotopic composition of Klondike oil as compared to Burger condensates and extracted oils and North Slope oil types

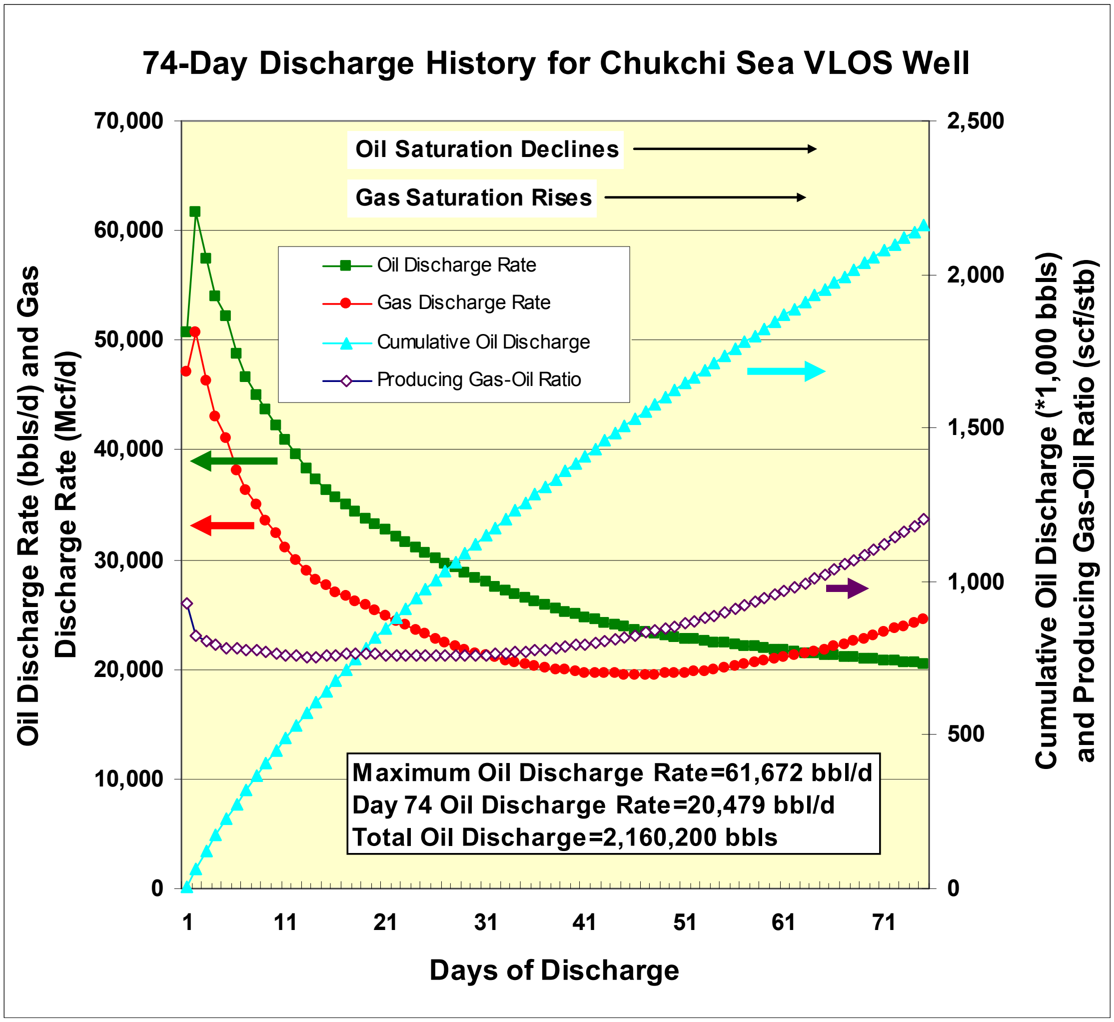

Figure D-3. Graph profiling daily oil and gas discharge rates, producing gas-oil ratio, and cumulative oil discharge over 74-day period of discharge from the Chukchi Sea VLOS well.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.